



# Small Engine Technology (SET) – Task 14 Axisymmetric Engine Simulation Environment Draft Final Report

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National Aeronautics and  
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This report contains preliminary findings, subject to revision as analysis proceeds.

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# **Small Engine Technology (Set) Task 14 Axisymmetric Engine Simulation Environment Final Report**

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## **1. SUMMARY**

As part of the NPSS (Numerical Propulsion Simulation System) project, NASA Glenn has a goal of developing a U.S. industry standard for an axisymmetric engine simulation environment. In this project, AlliedSignal Engines (AE) contributed to this goal by evaluating the ENG20 software and developing support tools. ENG20 is a NASA developed axisymmetric engine simulation tool.

The project was carried out jointly by NASA Glenn, NYMA, and AE. The work was centered around the ENG20 full engine simulation code. This code and its use in running an engine test case are described in Appendix I by Dr. Mark E. M. Stewart of NYMA.

The complete ENG20 engine simulation system was designed to operate with iterative coupling between the ENG20 code and AE compressor and turbine component streamline curvature codes. Evaluation of the complete ENG20 engine simulation system was approached in a systematic, logical fashion. Problems were encountered with the first ENG20 solution that prevented further evaluation of the complete ENG20 engine simulation system.

The most important results of the project are:

1. An evaluation of the complete ENG20 engine simulation system is not possible until the problems described in Appendix I are completely resolved.
2. The AE compressor and turbine streamline curvature codes were successfully linked with ENG20.
3. The GE Global Data System was successfully used to link the streamline curvature codes with ENG20.
4. An AE turbofan engine test case was used to evaluate the initial ENG20 solution. While a converged solution was obtained with ENG20, there were a number of serious discrepancies between the ENG20 solution and the AE engine cycle program results (see Table 1 in Appendix I).

## 2. INTRODUCTION

As part of the NPSS (Numerical Propulsion Simulation System) project, NASA Glenn has a goal of developing an US industry standard for an axisymmetric engine simulation environment. In this program (NAS3-27483), AlliedSignal Engines (AE) contributed to this goal by evaluating the ENG20 software and developing support tools. ENG20 is a NASA developed axisymmetric engine simulation tool.

The project was divided into six subtasks which are summarized below:

1. Evaluate the capabilities of the ENG20 code using an existing test case to see how this procedure can capture the component interactions for a full engine. Compare the solution results with publicly available design information and test data. Evaluate ENG20's ease of use, its order of accuracy, and convergence time.
2. Link AE's compressor and turbine axisymmetric streamline curvature codes (UD0300M and TAPS) with ENG20, which will provide the necessary boundary conditions for an ENG20 engine simulation.
3. Evaluate GE's Global Data System (GDS), attempt to use GDS to do the linking of codes described in Subtask 2 above.
4. Use a turbofan engine test case to evaluate various aspects of the system, including the linkage of UD0300M and TAPS with ENG20 and the GE data storage system. Also, compare the solution results with cycle deck results, axisymmetric solutions (UD0300M and TAPS), and test data to determine the accuracy of the solution. Evaluate the order of accuracy and the convergence time for the solution.
5. Provide a monthly status report and a final formal report documenting AE's evaluation of ENG20.
6. Provide the developed interfaces that link UD0300M and TAPS with ENG20, to NASA. The interface that links UD0300M with ENG20 will be compatible with the industry version of UD0300M.

The project was carried out jointly by NASA Lewis, NYMA, and AE. The work was centered around the ENG20 full engine simulation code. This code and its use in running an engine test case are described in Appendix I by Dr. Mark E. M. Stewart of NYMA.

Briefly, ENG20 is an axisymmetric Euler solver that solves for the flow through an entire engine. Since it solves the flow through the entire engine, the converged solution will include interaction effects between components including the compressor and turbine.

Currently, 1-D engine cycle simulation codes are used to incorporate interaction effects between components into the engine design process. One of the purposes of this project was to

determine whether component interaction effects could be predicted better using a 2-D axisymmetric engine simulation.

Because ENG20 does not model the detailed physics, special provisions were made to introduce blade force terms, pressure losses, heat addition due to combustion, bleed and coolant flows, aerodynamic blockage, and mixing in the nozzle. For this project, the information needed for the blade force and loss terms for compressors and turbines was computed by AE using 2-D streamline curvature codes. AE provided the streamline curvature codes and the engine geometry to use as a test case.

This report documents the work done by AE on this project. Results are presented and discussed. Finally, an assessment of the work is given under Concluding Remarks.

### **3. RESULTS AND DISCUSSION**

AE's overall objective in the project was to evaluate the capabilities of ENG20 based on computed results for an actual engine. The project also involved providing computed results for the engine's compressor and turbine from AE streamline curvature codes for use in the ENG20 solution.

#### **3.1 Information Coupling**

The information coupling between the streamline curvature codes, UD0300M and TAPS, and ENG20 was accomplished using GE's GDS. Subroutines were added to UD0300M and TAPS that saved pertinent information in GDS for use in the ENG20 simulation. Information saved at each computing station for each streamline was axial coordinate, radial coordinate, total pressure, absolute/relative flow angle, meridional flow angle, aerodynamic blockage, speed, and loss coefficient.

In addition, AE wrote a FORTRAN program that reads information from GDS and creates new input files for UD0300M and TAPS. The program reads the new boundary conditions from the ENG20 solution, stored in GDS, (inlet mass flow, inlet total pressure, inlet total temperature, and inlet flow angle), and creates new input files for running revised UD0300M and TAPS solutions based on the full engine simulation solution.

#### **3.2 Test Case**

AE provided coordinates for the entire gas path and locations of the blades and vanes in the TFE731-60 turbofan engine to NYMA for use as a test case for ENG20. Detailed performance predictions for the TFE731-60 turbofan engine obtained with the AE 1-D engine cycle simulation program (FAST) were also supplied for comparison with ENG20 solution results.

AE also ran 2-D streamline curvature solutions for the compressor and turbine components. The component programs were run off design to match an engine cruise operating condition (40,000 foot Cruise, Mach 0.8), defined by the AE engine cycle program. These compressor and turbine component solutions provided the necessary input boundary conditions for running the ENG20 simulation at this specified operating point.

In the early stages of the project, the results from the streamline curvature programs was supplied to Dr. Stewart in the form of a spreadsheet that contained flow angle, blockage, and loss definition for all blade rows within each component (FAN, LPC, HPC, HPT, LPT) for the TFE731-60 turbofan engine. The definition was extracted from the axisymmetric solutions matched at the defined operating point.

Later in the project, a GDS file was created for the low pressure compressor (LPC) using the subroutine written in UD0300M and the file was provided to NYMA. Dr. Stewart successfully read into ENG20 the information from GDS which was written by UD0300M.

No further use was made of GDS because difficulties encountered in the initial ENG20 solution prevented exercise of the coupled ENG20 / streamline curvature program system. Details on the difficulties encountered are found in Appendix I.

### **3.3 Evaluation of the Complete System**

The complete ENG20 engine simulation system was designed to operate with iterative coupling between the ENG20 code and the compressor and turbine component codes. The iteration process is as follows:

1. Flow solutions are obtained for the compressor and turbine using the component codes. The upstream and downstream boundary conditions for the component solutions are obtained from an engine cycle code.
2. Selected information from the component solutions including flow loss and turning information is stored in the GDS.
3. The component information is extracted from GDS and used to prepare an input set for ENG20.
4. An ENG20 solution is obtained using the latest component information.
5. Selected information from the ENG20 solution is written to GDS to be used as the upstream and downstream boundary conditions for the next component solutions.
6. The new upstream and downstream boundary conditions are read from GDS and used to modify the input sets for the component codes.
7. The component codes are re-run using the new upstream and downstream boundary conditions.
8. Steps 2 through 7 are repeated until the upstream and downstream boundary conditions for the component solutions converge.

Evaluation of the complete ENG20 engine simulation system was approached in a systematic, logical fashion. Steps 1, 2, 3, and 4 in the process outlined above were carried out first.

Then the solution from ENG20 in Step 4 was compared with results from the AE engine cycle code. This was an important step to validate the ENG20 solution; it was a reality check. Table 1 in Appendix I contains comparisons of selected parameters from the ENG20 solution and the AE engine cycle solution. While one would not expect the solutions to be identical, they should be relatively close.

Four problems with the first ENG20 solution are explained in some detail in Appendix I. AE provided as much assistance as possible to help NYMA solve these problems. However, the project ended before these problems could be resolved, therefore, it was not possible to exercise the entire 8-step process outlined above. Consequently, an evaluation of the complete ENG20 engine simulation system was not possible.

However, the ability to read the new upstream and downstream boundary conditions from GDS and modify the input sets for the component codes (Step 6 above) was demonstrated.

Task 6 in the statement of work, to provide the developed interfaces, which link UD0300M and TAPS with ENG20, to NASA was not completed because it was not funded.



#### 4. CONCLUDING REMARKS

The complete ENG20 engine simulation system was designed to operate with iterative coupling between the ENG20 code and AE compressor and turbine component streamline curvature codes. Evaluation of the complete ENG20 engine simulation system was approached in a systematic, logical fashion.

Problems were encountered with the first ENG20 solution that prevented further evaluation of the complete ENG20 engine simulation system. However, a number of conclusions can be drawn.

1. An evaluation of the complete ENG20 engine simulation system is not possible until the problems described in Appendix I are completely resolved. Thus it was not possible to determine whether component interaction effects could be predicted better by a 2-D axisymmetric engine simulation than with a conventional engine cycle code.
2. The AE compressor and turbine streamline curvature codes were successfully linked with ENG20.
3. The GE Global Data System was successfully used to link the streamline curvature codes with ENG20.
4. An AE turbofan engine test case was used to evaluate the initial ENG20 solution. While a converged solution was obtained with ENG20, there were a number of serious discrepancies between the ENG20 solution and the AE engine cycle program results (see Table 1 in Appendix I).



## **APPENDIX I**

### **AXISYMMETRIC, AERODYNAMIC ANALYSIS OF THE ALLIEDSIGNAL TFE731-60 ENGINE**

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## **1. Introduction**

This report is concerned with a joint project between AlliedSignal Engines (AE) and NASA Glenn to study axisymmetric full engine simulation techniques. The project involves coupling AE simulations of engine components with a NASA full engine simulation code (ENG20). The coupling method is to use the Global Data System (GDS) subroutine library to store solution information from each simulation and transfer this data to other simulations as needed.

The intended result of this work is to demonstrate an engine system simulation. In particular, the intent is to combine the physical modeling and predictive capability of detailed component simulations with the ability of an engine code to assimilate these component results into a full engine simulation. It is believed that the cost and quality of jet engine design should be improved with this ability to simulate an engine component within the engine system instead of in isolation.

This report details the steps taken in the project and explains the problems which had to be overcome in developing the full engine simulation.

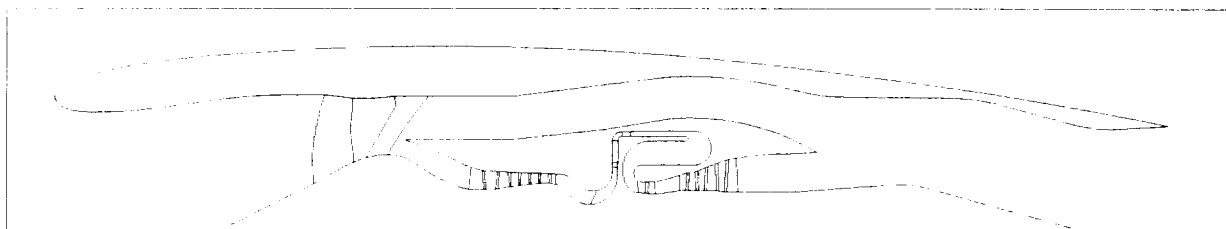
## **2. Preparing the Simulations**

The first phase of this work was to identify an engine to study, and develop the component and engine simulations used in the coupling process. AE has a modified version of the UDO300 code for streamline curvature analysis of fans, and high and low pressure compressors. Also, AE has an internally developed turbine analysis code called TAPS. Since AE has component simulations for its engines, no additional development of component simulations was necessary. However, since a full engine simulation did not exist for NASA's axisymmetric full engine code, ENG20, an engine simulation had to be developed, and this development is detailed in a following section.

### **2.1 The Simulation Engine**

The engine chosen for this study is the AE TFE 731-60 jet engine which is used on executive jet aircraft. The engine flowpath, as simulated, is shown in Figure 1 with the blade leading and trailing edges. This turbofan engine has a reverse flow combustor, a mixed axial-centrifugal compressor on two spools, and the bypass ratio is 3.9. The high pressure spool contains the centrifugal high-pressure compressor stage (HPC) and the single stage high-pressure turbine (HPT). The low-pressure spool joins the four-stage low-pressure compressor (LPC) and the three stage low-pressure turbine (LPT). The single-stage fan is geared off the low pressure spool.

The operating condition simulated in this study is Mach 0.8, 40,000 feet, and standard atmospheric conditions. At these conditions the wheel speeds are: fan - 9,698.57 rpm, low-pressure spool - 20,022.9 rpm, high-pressure spool - 29,204.2 rpm. The engine mass flow (cycle deck) is 57.521 lbm/sec.



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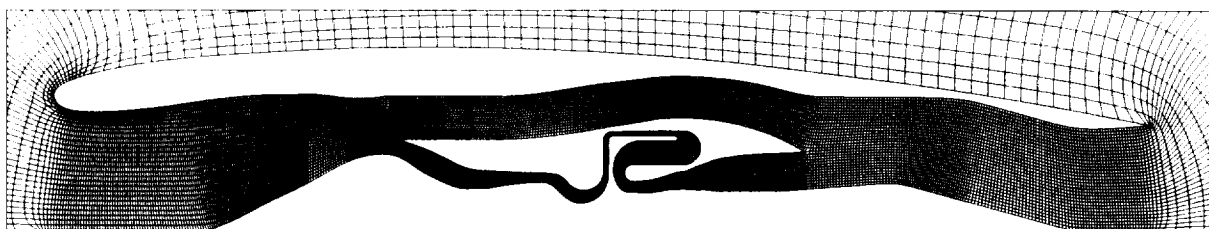
**Figure 1. Flowpath Geometry for the AlliedSignal ASE TFE731-60 Engine. The Reverse-Flow Combustor Geometry Is an Approximation.**

### **3. Development of the Axisymmetric Full Engine Simulation**

The ENG20 axisymmetric full engine simulation was developed in two steps. First, the engine geometry was compiled and a grid was developed which could be used in ENG20. Second, the ENG20 solution method was used to find a solution to the problem.

#### **3.1 Geometry and Grid Generation**

The flowpath geometry and blade locations for the AE TFE731-60 engine (Figure 1) were provided by AE, although the reverse-flow combustor geometry was approximated. This geometrical information was converted to a meridional plane grid with grid generation software developed by the author for complex 2-D geometries. This software breaks the engine components, connecting ducts and external field into a set of nonoverlapping, topologically rectangular regions. Each of these regions can be fitted with a 2-D structured grid where coordinate lines are continuous across the interfaces between blocks. This approach to grid generation is described in Stewart[1]. A coarsened version of this grid is shown in Figure 2. The grid used in the calculations is identical except that it has four times as many cells.



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**Figure 2. Coarse Grid for the AlliedSignal ASE TFE 731-60 Engine. The Actual Grid Contains Four Times as Many Cells, Namely 126,576 Cells.**

### 3.2 Solution Method

Throughout the meridional plane, ENG20 solves the inviscid Euler turbomachinery equations supplemented with terms for isentropic blade forces (flow turning), blade and combustor losses, and heat addition due to combustion. Bleed and coolant flow, aerodynamic blockage, and mixing due to a mixer are also supported. Details of the method are presented in Stewart[2].

ENG20 does not model the detailed physics of each engine component. Instead, the simulation determines the equation contribution from information provided by component codes. For example, the blade force on the flow through each blade row is determined from a turning distribution (absolute or relative flow angle and meridional angle) provided by a component code. ENG20 does not have incidence and deviation correlations or a 3-D blade model to predict the air angles or blade forces through a blade row. In a similar manner, losses are not determined by ENG20 from its own loss correlation or its own detailed calculation. Instead, the loss through a blade row is deduced from total pressure loss coefficients on a set of streamlines, and these must be provided by a component code. This approach to modeling physical effects and closing the equations is intended to emphasize the investment in developing component codes, and not duplicate this investment.

A significant problem in transferring this component information between the component codes and the full engine code is geometrically locating component information in the full engine grid. Blade turning distributions, losses, and other quantities must be mapped onto the grid with sufficient accuracy before they can be used. To solve this problem, a geometrical search procedure is used to locate blade rows within the full engine grid and interpolate data onto this grid.

The numerical solution of this engine model is found by using a multi-stage Runge-Kutta scheme with artificial dissipation and local time-stepping. This numerical solution procedure executes in parallel on a set of networked workstations or a parallel supercomputer.

As this simulation is formulated, there are four control parameters: the two wheel speeds (RPM1 and RPM2 in input files), the far field Mach number (MACH in input files), and the combustor efficiency (EFFIC in input files). Back pressures do not need to be specified for components within ENG20 since simulating the entire engine system circumvents this issue. The UDO300 and TAPS simulations do need to have back pressures specified. The wheel speeds are specified and not determined from a torque balance because shock turning is not captured in this engine model.

An engine numerical solution cannot be found by specifying these four simulation control parameters and impulsively starting the simulation. Instead, the solution must be brought to the simulation condition by slowly increasing the control parameters. It is also necessary to heavily dissipate the solution during its development since extreme off-design conditions are encountered. When the simulation condition is reached, the stabilizing dissipation is reduced.

### **3.3 GDS interface**

The exchange of information or interfacing of the engine component and engine codes is achieved through the GDS subroutine library. GDS or Global Data System was written by Jim Keith at General Electric Aircraft Engines (GEAE). This subroutine library was provided to ASE by GEAE during the project to perform the necessary exchange of information.

Information is exchanged between codes with GDS by having the programs deposit and withdraw named (or labeled) pieces of information from a hierarchical database. These deposits and withdrawals are performed with GDS subroutine calls placed within a simulation code. GDS transmits data by using PVM messaging within a parallel computer or networked workstations. GDS also has subroutines which allow programs to synchronize themselves during parallel execution.

AE's UDO300 and TAPS codes were modified to include GDS subroutine calls. After these codes perform their calculations, GDS subroutine calls deposit some solution results in the GDS database. This data, required by the engine code, is of two types. First, the turning distribution is required (the absolute air angle for stators, relative air angle for rotors, and meridional angle) through a set of streamlines across the span of each blade. Second, the total pressure loss coefficient through a set of streamlines spanning each blade row is required. Again using GDS subroutine calls, the engine code retrieves the turning distribution and loss data for each blade row.

Before being used in the full engine code, the information retrieved from GDS must be interpolated onto the full engine grid. Consequently, a geometrical search algorithm is used to locate the blade information in the full engine grid and interpolate it.

Having ENG20 provide boundary data for the component codes occurs in a similar way. After completing a fixed number of solution iterations, ENG20 uses interpolation and its solution to determine enthalpy or pressure along the inflow and outflow boundaries used by the component codes. This information is deposited into GDS where it can be retrieved by the component codes.

This coupling of the engine and component codes requires an exchange of information after progress in each contributing solution. Consequently, the exchange of information occurs many times and involves some overhead.

## **4. Simulation Results and Developmental Problems**

The ENG20 simulation of the AE TFE731-60 engine was developed and started as described in Section 3. In Table 1a and 1b, the solution results are compared with the results of AE cycle deck program for the cruise operating point. In general, the comparison is favorable with differences of only a few percent. The most significant discrepancy is the total pressure loss through the high and low pressure compressors.



**Table 1(a). Comparison of Solution Results with AE Cycle Deck Program for Cruise Operating Point.**

**M=0.8; 40,000ft; Standard Atmospheric Conditions**

Engine Station	Flow Quantity	% Difference
Fan Inlet	$P_0$ (psi)	+0.0
	$T_0$ (degrees F)	-0.7
	$\dot{m}$ (lb/s)	+2.4
Fan Outlet	$P_0$	+2.2
	$T_0$	+1.8
	$\dot{m}$	+2.5
LPC Inlet	$P_0$	-0.5
	$T_0$	+1.2
	$\dot{m}$	-1.8
LPC Outlet	$P_0$	-2.7
	$T_0$	-1.5
	$\dot{m}$	-1.0
HPC Inlet	$P_0$	-3.4
	$T_0$	-1.4
	$\dot{m}$	+0.8
HPC Outlet	$P_0$	-9.3
	$T_0$	-2.3
	$\dot{m}$	+2.5
HPT Inlet	$P_0$	-15.9
	$T_0$	+1.0
	$\dot{m}$	+5.8
HPT Outlet	$P_0$	-13.5
	$T_0$	-5.5
	$\dot{m}$	+4.3
LPT Inlet	$P_0$	-13.3
	$T_0$	-4.9
	$\dot{m}$	+5.5
LPT Outlet	$P_0$	+7.2
	$T_0$	-0.8
	$\dot{m}$	+4.6

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**Table 1(b). Comparison of Solution Results with AE Cycle Deck Program for Cruise Operating Point.**

Engine Station	Flow Quantity	% Difference
Fan	$N_{corr}$ (rpm)	0.
	$\dot{m}_{corr}$ (lb/s)	+6.5
	$P_0$ Ratio	+6.1
	$T_0$ Ratio	+1.4
LPC	$N_{corr}$	0.
	$\dot{m}_{corr}$	-2.6
	$P_0$ Ratio	-11.5
	$T_0$ Ratio	-2.9
HPC	$N_{corr}$	+1.2
	$\dot{m}_{corr}$	+10.1
	$P_0$ Ratio	-4.3
	$T_0$ Ratio	-0.3
HPT	$N_{corr}$	+0.4
	$\dot{m}_{corr}$	+18.5
	$P_0$ Ratio	+0.5
	$T_0$ Ratio	+1.3
LPT	$N_{corr}$	+0.5
	$\dot{m}_{corr}$	+19.1
	$P_0$ Ratio	-21.8
	$T_0$ Ratio	-4.7
Engine System	BPR	+5.6
	Fuel Flow (lb/hr)	-4.4
	N1 Actual	Specified
	N2 Actual	Specified
	Fan (Geared from N1)	Specified

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The development of the AE TFE731-60 full engine simulation involved solving several problems. It has not been possible to fully resolve one of these problems, namely the discrepancy in total pressure loss through the compressor sections. Because of this discrepancy in performance, it is not practical to perform the iterative coupling of the ENG20 engine solution and the AE component simulations. These solution discrepancies would not provide meaningful updates to the component simulations.

## **Problem 1: Low and High Pressure Compressor Performance**

The total pressure rise achieved through the low- and high-pressure compressors is below the predictions of the cycle deck. The underlying reason is theoretical, namely, the blade model of the axisymmetric equations does not perform like the three-dimensional blade model, particularly with regard to shocks. Blade axisymmetric shocks differ from the true 3-D ones. Consequently, the shock losses also differ. The numerical treatment of the axisymmetric blades must account for these differences.

One contributing error was "double-bookkeeping" shock losses through blade rows. The axisymmetric equations admit shocks and their losses, however the imposed total pressure loss duplicated the shock losses. The numerical method for imposing the total pressure loss was modified, however, the resulting scheme can only be used with first-order dissipation instead of third-order dissipation. First-order dissipation introduces more loss and smearing than the third-order form. If higher-order dissipation could be used, then compressor losses would decrease.

A further factor contributing to losses is a supersonic region in the centrifugal impeller corresponding to choking. As the engine core mass flow decreases, so does this supersonic region. The decreased performance of the low pressure compressor helps choke the impeller.

## **Problem 2: Inlet Shock**

During the development of the solution, a weak normal shock was always present in the engine inlet. The ENG20 solution indicates the steady-state mass flow is 2 to 3.5 percent above the mass flow predicted by the cycle deck. The inlet throat area is 3.45 percent greater than the choking area for the design mass flow. Discussions with a NASA inlet designer indicate that the inlet design is reasonable given the design mass flow and the operating condition.

The maximum Mach number in this shock is  $M = 1.3$ . The flow solution in the inlet is an inviscid flow solution (Euler equations), and consequently there are no viscous boundary layers. This shock persists despite a large number of solution iterations which should remove most startup transients.

## **Problem 3: Matching Turning Distributions**

A minor limitation of the engine code's blade force source terms is that if the air angle at the blade leading edge does not match the anticipated turning distribution, then numerical losses are introduced as the flow direction is aligned to the prescribed turning distribution. These losses can degrade the simulated performance of the turbomachinery.

It is expected that there will be some small deviations between the engine simulation and the component codes, in particular with the turning distribution at the blade leading edges. This problem is accounted for by modifying (smoothing) the turning distribution near the leading edge of each blade so that it agrees with the incoming air angle. By using this technique the numerical losses are essentially removed.

One problem during development concerned how much of the turning distribution to smooth. The original treatment was to smooth the entire span and chord of the blade row to avoid slope discontinuities. For the HPC impeller this treatment changed the turning distribution excessively and gave span-wise flow gradients and stagnant regions. Smoothing is now limited to the leading edge region of each blade.

#### **Problems 4: Combustor Fuel Addition and Bleed/Coolant Flows.**

A further problem solved during development was improper metering of fuel into the combustor. The fuel mass flow was 15 percent low and turbine temperatures were low.

Poorly adjusted bleed and coolant flows changed the core mass flow by up to 4 percent. This problem was repaired and the discrepancy was corrected.

### **5. Conclusions**

The dominant problem with the current simulation is the total pressure loss through the high- and low-pressure compressors. The need to use first-order dissipation contributes to this discrepancy. The high corrected mass flow of the high pressure compressor and resultant shocks is a further contributor. Improvement of the simulation should concentrate on reducing losses and increasing performance of the compressor sections.

### **6. Bibliography**

Stewart, M. E. M., "Domain Decomposition Algorithm Applied to Multi-Element Airfoil Grids," AIAA Journal, Vol 30, #6 pp 1457-1461.

Stewart, M. E. M., "Axisymmetric, Aerodynamic Numerical Analysis of a Turbofan Engine," ASME Paper 95-GT-338.



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